Driving Requirements for Advanced Space Telescopes

Charley Noecker
Jet Propulsion Laboratory,
California Institute of Technology
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The trends for space telescopes

• Larger
  – James Webb Space Telescope (JWST) 6.5 m
  – Terrestrial Planet Finder (TPF) 4-8 m
  – Advanced Technology Large-Aperture Space Telescope (ATLAST)
  – GEO imaging and earth science (MOIRE) >20 m

• More stable
  – JWST 150 nm for 2 weeks
  – TPF and its smaller precursors <0.01 nm RMS for 4-24 hours
  – WFIRST and Euclid, looking for dark energy via weak-lensing
  – Earth observing <50 nm despite rotisserie effects

• Visible and UV wavelengths

• Cheaper (?)
JWST is calibratable, not calibrated

- Telescope testing will **not** prove it’s aligned with good wavefront—only that it **can be** aligned on orbit, within the actuator range
- **A brave new paradigm in design, build, and especially test**
- On-orbit performance goal is modest — diffraction limited at 2 µm
- Traditional optical testing with large system in cryo is very high risk
- JWST approach allows
  - Millimeter and sub-mm vs. few-nanometer measurement uncertainties
  - Coarse optical alignment instead of fine alignment
  - Component and subsystem testing to demonstrate fine performance
  - Lower stiffness and mass
  - Larger gravity deflections and offloading uncertainties
- Testing is focused on actuator range vs. uncertainties in alignment state after launch & deployment
- Design the range of actuator motion to cover those uncertainties
- In test, compare actuator range to the measured uncertainties
The future is more difficult

- JWST is only diffraction limited at 2 µm — wavefront ~ 150 nm
- Next generation observatories require much higher stability, or larger size, or both
- Continuing pressure for lower mass
- Folding to fit in launch vehicles
- Increasing challenges for pre-launch verification
- Breaking the chains of a single launch vehicle

→ How to build a telescope that takes multiple launches?
JDEM weak lensing requires stable WF

- JDEM, WFIRST, Euclid: **1-2 meter diameter**, NIR to visible
- Measurement of cosmological dark energy via weak gravitational lensing (one of three methods)
- Requires high-precision statistical measurement of mean ellipticity of thousands of galaxies
  - Net distortion arising from gravitating mass & energy near the line of sight
- Galaxy ellipticities can be biased by telescope PSF ellipticity
  → Telescope wavefront errors
- Tight requirements on knowledge of PSF shape and PSF changes
  → Tight requirements on wavefront accuracy and stability

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Terrestrial Planet Finder coronagraph

• TPF-C: **4-8 m** visible telescope for direct detection of exoplanets
  – Isolating the planet light from its host star’s light, analyzing spectrum
  – Search for habitable planets and spectroscopic signatures of LIFE

• Planet star contrast is extreme: typically $10^{-10}$ and <0.5µrad apart

• For internal coronagraph, this requires wavefront stability about 10 picometer ($10^{-11}$ meter) rms for 4-24 hours (TBR)

• This is hard to do by passive means, but modeling has shown that this performance may be reachable in a benign orbital environment

• Pre-launch verification is an unsolved challenge

• Extremely precise internal metrology of the telescope could make both verification and on-orbit challenges easier to achieve
MOIRE: toward a “space ELT”

• DARPA program to develop technologies for 20 m diameter visible telescope for high-resolution Earth imaging from GEO

• Diffraction-limited performance in the visible, despite being totally exposed to Sun and Earth thermal disturbances
  – Long focal length, low-CTE materials and low emissivity, OR
  – Metered by optical sensors and actively controlled

• Present design uses holographic optics in transmission
  – Micron-scale radial stability; centimeters axial

• Future designs may move toward reflective optics for improved bandwidth
  – ~20 nm opto-mechanical stability needed

Artist’s concept
Credit: DARPA
Increased reliance on controls

- Optical trusses provide stability, accuracy, repeatability with modest mass
- Laser metrology can provide nanometer-scale knowledge of optic positioning
  - Active or adaptive control can correct errors that occur elsewhere
- Many factors can be mutually traded
  - Structural materials and mounting
  - Mirror segmentation
  - Thermal control
  - Actuator range
  - Density of sensing and actuation
  - Deployment accuracy
  - Verification accuracy
- Active vs. passive for control, accuracy
Ready, Fire, Aim — I&T after Launch

• Eventually telescopes will be too big to launch
• Self-deployment is not enough; self-assembly will be necessary
• Segmented big mirrors are launched in pieces
  – Perhaps 2-10 launches over many years
  – Allows easy replacement of disabled pieces

• In this scenario, what is Integration and Test, and what’s it for?
  – Subassemblies are proven individually on the ground
  – Somehow must prove before launch that the parts will work as a unified whole, without a full-up test
    • SYSTEM engineering, SYSTEM test
  – Heavy reliance on model-based performance verification
  – Absolutely not “test-as-you-fly”
Brave New World

- JWST has opened a gate to a wider pasture
- New risks and opportunities